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PRELIMINARY STUDY OF WHITE SPRUCE IN MINNESOTA

BY

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FOREST EXPERIMENT STATION, CLOQUET

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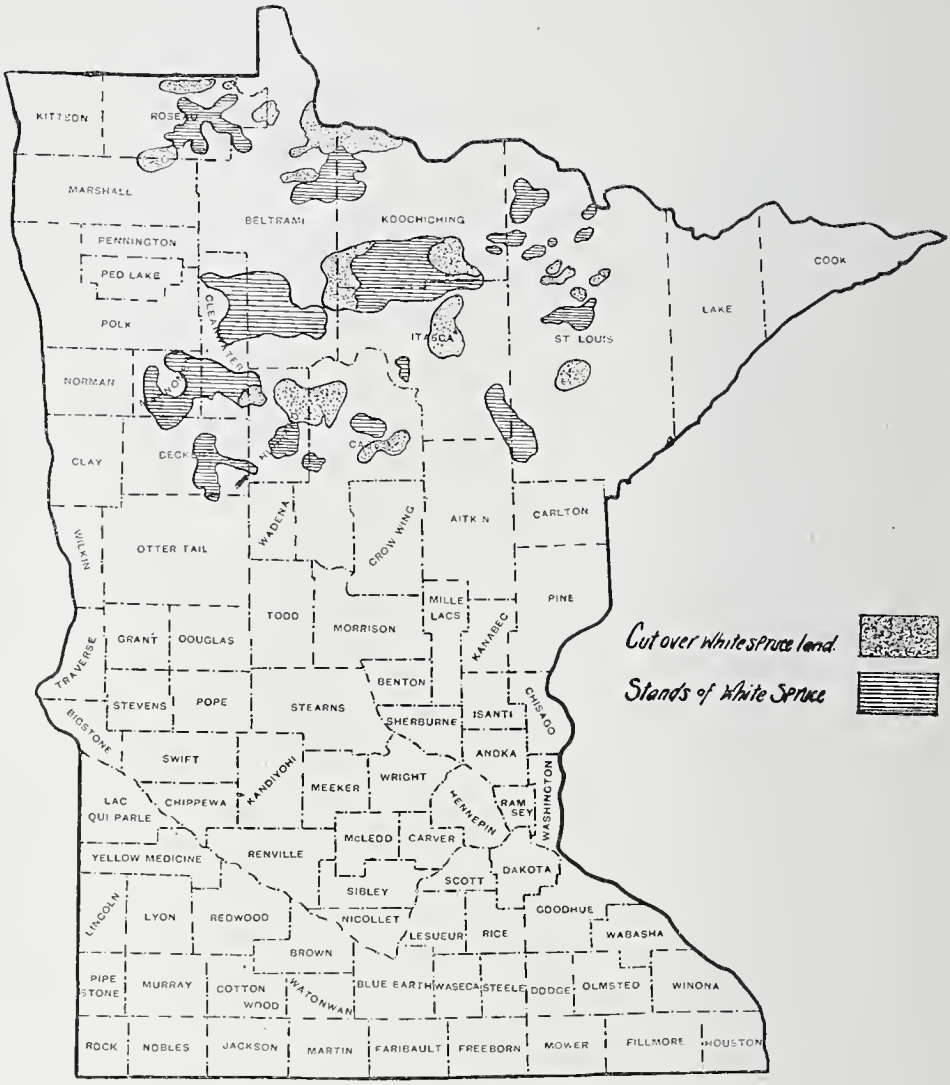

Fig. 1. Location of Best White Spruce Land

PRELIMINARY STUDY OF WHITE SPRUCE IN MINNESOTA

By W. H. Kenety

INTRODUCTION

The data obtained on growth, yield, and distribution of white spruce in the state have been assembled and the approximate returns which may be expected from young stands or plantations determined. Since little information on this species has been published it is thought that this study, tho not complete in itself, will be helpful to the state in its reforestation work, to the individuals who have land suited to spruce, or to corporations that may wish to grow a perpetual supply of spruce for industrial purposes.

The writer wishes to acknowledge the valuable assistance of G. H. Wiggin, A. F. Oppel, and K. J. Braden in collecting data, and of J. H. Allison who aided in the collection of data on volume studies and gave helpful suggestions on taxation principles.

Spruce constitutes approximately eighty-five per cent of the wood which goes into the manufacture of newspaper. Several species are used, the red spruce in the eastern states and the black and the white spruce in the Lake states. Of these, white spruce produces the best fiber and grows most rapidly.

The increasing scarcity of spruce for pulpwood and the attendant increase in the cost of paper make it imperative that the supply of pulpwood be perpetuated if the industries depending on this supply for their existence are to continue, and if the cost of paper is to be kept within reasonable bounds.

In the manufacture of paper, the two prime requisites are cheap wood for pulp, and water power. The means and the cost of obtaining the latter are very carefully studied and provided by the manufacturers, but the testimony of many of the leading lumbermen and paper men before a committee of representatives of Congress on paper and pulp investigations, in 1909, showed that very little information was available and that not enough study had been given to the economic source of pulpwood. An investment of several million dollars often depends upon this supply. The testimony of a large number of paper men and pulp companies who made a close canvass of conditions in connection with a federal inquiry into the paper industry in 1917, showed quite convincingly that the exhaustion of the supply of pulpwood is largely responsible for the present high price of paper.

Fully one fourth of the pulp and paper used in this country is imported, a large percentage from Canada. In 1908, Canada imposed extra duties on pulpwood in the eastern provinces. It is possible that other duties will be imposed, in order that Canada may prolong her supply of wood for her own mills.

The Laurentide Paper Company, one of the largest paper companies operating in the St. Lawrence Valley, has made a careful estimate of the pulp resources of that region and predicts that unless very vigorous efforts are made to protect pulpwood from fire and to restock cut-over lands, the supply in the St. Lawrence Valley will be exhausted within fifteen years.

The virgin spruce supply of Minnesota is being rapidly exhausted. This is partly because the paper mills in Wisconsin now obtain a large part of their pulpwood from Minnesota. The supply of spruce in Wisconsin was at one time thought sufficient to last the paper industries of that state for all time, but it is now nearly all cut. It will be only a short time until the mills of Minnesota will be unable to get pulpwood, unless measures are taken to protect the young growth and to reforest the land in Minnesota which is admirably adapted to the growing of white spruce.

David F. Houston, Secretary of Agriculture, in an article published March 17, 1917, suggested that the spruce in the western forests and Alaska be used to supply the needs of paper men and publishers. This might be a good plan for the western consumers and also for the eastern users after the war. With the return of normal shipping conditions, it might be possible to ship paper or pulp to the east coast region by way of the Panama Canal cheaply enough to make this scheme possible, but it would be prohibitive to the paper manufacturers and the publishers of the Middle West. The freight alone on pulp or paper from the western coast towns to the Twin Cities is $15 a ton in carload lots. The rate from Cloquet to the Twin Cities is $1.64 per ton in carload lots, and from International Falls, the farthest removed paper mill in the state, $2 per ton.

A cord of spruce pulpwood weighs 2¼ tons when green and from 1½ to 1¾ tons when dry; and as will be shown later, from 5 to 7 cords of spruce can be produced in Minnesota for the cost of freight alone on a single cord of wood in carload lots from Seattle. Hence shipping pulpwood from the western states to Minnesota mills would be out of the question.

Therefore the only means of getting an adequate supply of pulpwood for the Lake states seems to be (1) protecting the young growth, and (2) planting the cut-over spruce lands. In studying the advisability of planting or managing a spruce forest as a source of raw material for a pulp mill, the cost of transporting raw pulpwood for

long distances and the loss from fire in inaccessible regions of virgin supply are items that should be carefully balanced against a perpetual supply of wood readily accessible and easily protected and handled, as it would be in a managed forest.

Box factories, crating mills, excelsior plants, chemical utilization plants, and the use of preservatives have now greatly increased the value of the fast growing woods such as popple, white pine, white birch, and balsam fir which grow in mixture with the white spruce. Much of the land suited to the growth of white spruce carries a fair stand of these heretofore worthless species which can now be used and made to pay for the introduction of the more valuable spruce. These new uses of quick maturing associate species, eliminating the long-time investment, the high price of stumpage, arising from the increasing scarcity of lumber in the Lake states, and the great reduction in fire risk through the state and private fire patrols, have so changed conditions that the deductions made ten years ago as to the advisability of reforestation and the suitability of certain species to forestation are no longer applicable. The advisability of using suitable lands, both private and state, for the growth of white spruce and its associate species is much greater than it was a decade ago.

WHITE SPRUCE *(Picea canadensis)*

White spruce, also known as cat or upland spruce, altho limited in its range to a cold climate, is a tree of wide distribution. It extends from Maine to the northwestern corner of Minnesota. It is found in the Black Hills and extends in scattered stands to Alaska and the Arctic Ocean. White spruce grows faster than the black spruce of our swamps, or the red spruce of the East, and, altho sometimes called upland spruce and confused with these species, it has several distinguishing characteristics. The young branches, especially when crushed, have a strong fetid odor. The young twigs and ends of the branches are smooth, while those of the black spruce are covered with a brownish fuzz. The cones of the white spruce are quite long and slender in comparison with those of the black spruce, which are short and round. The cones of the white spruce drop off each year after the seed have fallen out, while those of the black spruce, clustered in the top of the tree, sometimes remain for ten or fifteen years. The wood under the bark of the white spruce is a light color, while that of the black spruce is a brownish yellow. This means of identification is often used in a stand where no branches or cones are near. A small blaze on a tree will usually be sufficient to reveal the color.

The branches of the black spruce are short and clustered near the

top while those of the white spruce are longer and scattered more openly along the stem, forming a long crown. The average woodsman can usually tell them apart by the bark and the difference in the general shape, but the two trees are often so similar that some of the differences given must be noted in order to distinguish the two species.

SOIL

White spruce is nearly always found on rich, moist soil—generally lake or river drift. Soil seems to be the determining factor in its growth. White spruce is found in many conditions of climate, but always on rich drift soil. It does not grow in swamps as does the black spruce. The term "upland spruce" is a misleading term, because in the northeastern part of the state stands of black spruce mixed with jack pine are often found on high, rocky cliffs.

CHARACTERISTICS OF WHITE SPRUCE SOIL

A large part of the forest region of Minnesota has been cut over and burned over. It is of glacial origin and contains many kinds of soil, some of which are suited to white spruce, while others are better suited to other species. Owing to the ravages of fire, it is very difficult to tell from the vegetation alone whether any particular land is suited to the growing of white spruce.

In order to classify the soil, some standard is necessary. The best standard for this purpose so far determined at the Cloquet station, is what is known technically as the "moisture equivalent" determination. Roughly speaking, this standard gives the amount of water in the soil available for tree growth.

Many foot samples of soil were taken to a depth of five feet on areas in widely separated regions in northern Minnesota, where white spruce made the best development. These soils were used as a standard for comparing cut-over and burned-over areas on which there was no white spruce, to determine whether they were suited to that species. If the moisture equivalent of the soil in any of these barren areas was found to be similar to those of areas with fine stands of spruce, they were classed as white spruce land. In fact, the correlation between the moisture equivalent and the rate of growth has been found sufficiently definite to warrant a rough estimate of the probable yields on the basis of this one factor.

Plots were selected in the best stands to be found in all of the representative spruce regions of the state. In each plot studied, from four to six foot samples of soil were taken to a depth of five feet. All the first foot samples in each plot were mixed together to obtain an average. The same was done with the second, third, fourth, and fifth foot samples respectively.

These samples were sent to the Division of Soils, of the Agricultural Experiment Station and the moisture equivalent of each sample was determined. The results of these determinations are given in Table I.

TABLE I
MOISTURE EQUIVALENT DETERMINATIONS OF WHITE SPRUCE SOIL

Location	First foot	Second foot	Third foot	Fourth foot	Average
	Per cent	Per cent	Per cent	Per cent	Per cent
Warroad	16.5	14.2	12.6	10.7	13.5
Northome	23.5	24.5	25.5	22.0	23.9
Effie	35.8	37.8	34.7	32.7	35.3
Horse Lake.....	17.0	11.1	*	*	...
Cook	36.9	48.0	43.4	36.9	41.3
Average.....	28.8	31.3	29.2	26.1	...

* Rock.

The average of a large number of samples of pine soil taken in the vicinity of Cloquet shows the big difference in this respect between the white spruce soils and the pine soils. Table II is based on the average samples in this vicinity.

TABLE II
MOISTURE EQUIVALENT DETERMINATIONS AT CLOQUET

Species	First foot	Second foot	Third foot	Fourth foot	Average
	Per cent	Per cent	Per cent	Per cent	Per cent
Jack pine.....	7.9	4.7	2.6	2.0	4.3
Norway pine.....	9.1	5.2	3.6	2.9	5.2
White pine.....	14.3	6.7	5.6	3.4	7.5

From the above figures, it is clear that white spruce is naturally adapted to a soil which is comparatively heavy for at least four feet in depth. Pine, on the other hand, will live and grow in a much lighter soil, because its more extensive root system penetrates deeper and enables it to use the water located at lower levels.

Even in the young seedlings, the difference between the root systems of spruce and pine is quite marked.

Nobbe grew seedlings of pine and spruce in large glass vessels and measured the roots.[1] The results were as follows:

[1] Jost, Ludwig. Lectures on plant physiology, Gibson's translation, p. 27. pp. 564. 1907.

TABLE III

Comparison of Root Systems of Pine and Spruce

Species	Number of roots	Proportional value	Total length of roots	Proportional value
			Feet	
Pine	3,135	24	39.33	12
Spruce	253	2	6.37	2

As the young trees grew larger, the difference between the roots of the two species was more striking. Because of its more extensive root system, the pine makes much better use of the limited water supply in sandy soil, and will grow where the spruce will not.

DISTRIBUTION

White spruce is distributed in more or less scattered areas over nearly all of Northern Minnesota that is forested. There are 3,120,000 acres of land in Northern Minnesota on which white spruce is still standing or from which it has been cut. White spruce is being cut off very rapidly.

The map, Figure 1, shows the distribution of white spruce in Minnesota.

TYPES

White spruce is not found in pure stands. In fact, it is quite rare to find white spruce composing more than half of the stand in any region. It is generally found mixed with popple, balsam, or white

Fig. 2. Typical Stand of Black Spruce and Jack Pine With Occasional White Spruce, on High Moss-Covered Rock, Horse Lake

pine, and sometimes with all three. It also associates with balm of Gilead, tamarack, black spruce, cedar, and a few hardwoods, as birch and elm. The percentage of the different species obtained from sample areas in different parts of the state, is given in Table IV.

TABLE IV

SPECIES IN ACRE PLOTS IN SPECIFIED LOCALITIES

Species	Cook	Warroad	Northome		Effie	
Total number of trees	606	370	204	142	164	220
	Per cent	Per cent	Per cent	Per cent	Per cent	Per cent
White spruce	89	21	20	69	52	58
Balsam	4	9	40	12	6	..
Poplar	3	32	6	1	8	35
Tamarack	2	2	2	..	..	..
Black spruce	2	2	..	4	4	3
Elm*	..	3	2	7	10	..
Balm of Gilead	..	7	1	..	4	..
Green ash	..	24	1	..	4	..
Cedar	..	..	2	..	..	..
Oak*	..	..	2	..	..	..
Birch	..	..	2	4	12	..
White pine	..	..	2	1	..	1
Maple*	..	..	20	1	..	2
Jack pine	..	..	..	1	..	1

* Most of the elm, oak, and maple are very small and none reached a merchantable size.

AREAS STUDIED

While the vegetation generally associated with the well-stocked white spruce types of forest varies slightly on account of the different densities, it is generally uniform. The predominating species found in different parts of the state are as follows:

In the region of Horse Lake, Twp. 65 N., R. 11 W., Sec. 29, the whole country is rough and rocky with very little soil cover; in some places the soil has collected in pockets from one to three feet deep. (See Figures 2, 3, and 4.) In these pockets are found some popple and birch, the latter not very well developed. Dwarf maple and balsam comprise the underbrush. On the rocky hills and knolls black spruce and jack pine predominate. The soil in this type is very shallow and consists largely of broken rock covered with moss which holds enough water to keep the trees supplied. There is very little underbrush except scrub cedar and blueberry.

In the region of Warroad, Twp. 163 N., R. 37 W., Sec. 1, the soil is lake-washed till running somewhat to clay, with a heavy black

Fig. 3. Solid Rock Land on Which the Stand Shown in Figure 2 Grew

humus loam from six to ten inches deep on top. The predominating forest type is popple and white spruce, with some balsam and tamarack. The brush is small red maple, green ash, dogwood, alder, raspberry, and some scattered willow. The ground cover is moss, strawberry, partridge berry, goldenrod, Labrador tea, redtop, and bluejoint.

In the region of Northome, Twp. 151 N., R. 29 W., Sec. 25, the soil is a morainic land-laid clay. The clay is very heavy, with little humus cover and few rocks. The underbrush is quite thick and ranges up to ten feet in height. It is mostly maple, elder, and hazel. The ground cover is moss and there is very little herbaceous growth, mostly ground dogwood, honeysuckle, and grass.

In the region of Effie, Twp. 62 N., R. 26 W., Sec. 26, the soil is a very heavy morainic clay very much lacking in humus. The lower two feet are very calcareous. The underbrush consists of alder, green ash, and red maple, and the ground cover of moss, grass, and fern, some elm, and dwarf maple. The type here is mixed white pine, white spruce, and popple.

In the region of Cook, Twp. 62 N., R. 18 W., Sec. 17, the soil is heavy, laid-down clay with a good deal of lime and very little gravel within five feet or more of the surface, and with very little organic matter. The underbrush is medium thick except in open places and consists of maple, green ash, and some elder. Grass, mosses, and dwarf dogwood form the ground cover.

USES

The United States uses annually about three billion board feet of spruce of all species, for lumber and pulp.

The use of pulp wood for newspaper stock has increased since 1890. Between 1899 and 1909 the increase was about five per cent a year. Since 1915 it has been about sixty per cent. The recent investigations of the Federal Trade Commission show that 1,800,000 tons of newspaper were used last year. This means that about 2,700,000 cords of spruce were used for newspaper alone, estimating that about eighty-five per cent of the newspaper is made from spruce. Minnesota mills use annually about two hundred and fifty thousand cords of spruce for the manufacture of newspaper.

Fig. 4. White Spruce Uprooted
The rock subsoil is seldom more than two feet below the surface.

Spruce is used in the manufacture of many other products. About 7,250,000 board feet of spruce are used annually for veneer. Spruce is the wood most used in the manufacture of aeroplanes. The beams and frame work are nearly all spruce, either clear sticks or laminated strips glued and fastened together so that any weaknesses in one strip will not extend through the whole piece.

The percentages of spruce used for factory purposes are:

	Per cent		Per cent
Mill work	44	Woodenware and novelties	4
Boxes and crates	42	Tanks and silos	1
Musical instruments	4	Miscellaneous	5

The percentage of woods used in the structure of aeroplanes as given by Kellogg[2] is as follows:

	Per cent		Per cent
Spruce	63	Yellow poplar	6
Ash	16	Oak	5
Mahogany	8	Hickory	2

Spruce is also used for:

Agricultural implements	Fiber board	Moldings
Aeroplanes	Fixtures, backing and lining	Organ pipes
Boats		Paddles
Oars	Fixtures, office	Piano backs
Bowling alleys	Flat poles	Piano sounding-boards
Boxes	Flooring	Ships
Broom handles	Furniture	Shiplap
Butter tubs	Guitars	Silos
Cable reels and spools	Hay presses	Sleds
Cameras	Ice boxes	Spars
Canoes	Interior finish	Tables
Car sheathing	Key boards	Tanks
Crates	Ladder slides	Tubs
Doors	Mandolins	Vehicles
Elevator platforms	Match cases	

LENGTH OF FIBER

White spruce has a longer fiber than any of the other spruces. According to a Government bulletin,[3] the length of the fiber of the different spruces is as follows:

TABLE V

LENGTH OF WOOD FIBER

Species	Average	Maximum	Minimum
	Inches	Inches	Inches
White spruce	0.14	0.19	0.06
Red spruce	0.13	0.16	0.07
Black spruce	0.1	0.15	0.08

From this table it will be seen that, from the standpoint of length of fiber, white spruce is best for paper-making and probably allows the use of more balsam and other inferior, short-fibered woods.

[2] Kellogg, R. S. Lumber and its uses. pp. 352. pl. Radford Architectural Co., Chicago, 1914.

[3] Zon, Raphael. Balsam fir. p. 32, U. S. D. A. Bull. 55. pp. 68. 1914.

GROWTH

Sample plots averaging one acre in extent were selected in all of the regions studied. In most of the regions, three or four plots and sometimes five were measured. These plots were always located in the best stands because they most nearly represent the possibilities of the soil. Unfavorable conditions would be eliminated under management, and growth would be limited largely by the quality of the soil. Local forest rangers and residents were consulted in finding these stands, so that the plots may be said to be typical.

The region near Horse Lake, in Lake County, is typical of much of the country in northeastern Minnesota. According to the analyses (See Table I), the soil is considerably lighter than any of the other spruce soils studied. The ratio between the moisture equivalent of this soil and that of the average of the other soils studied was about one to two in the first foot and slightly less in the second one. As a consequence, this region, which according to meteorological records has as heavy a precipitation as any other part of the state, does not support white spruce so well as the heavier soils. The shallow soil, with its smaller water-holding capacity and permeable subsoil, which is usually broken rock, supports only those trees which are adapted to adverse conditions. White spruce in this region is found only in pockets where deeper soil and drainage provide an abundance of water. In this region Jack pine is usually mixed with spruce, and in most places composes the greater part of the stand. White spruce averages from six to eight trees, scaling not quite two cords to the acre. Typical trees in good locations reached a diameter, breast high, of twelve inches in about one hundred years, and an average height of 74 feet. Black spruce growing in the same plot was one hundred and two years old on the average, 7.1 inches in diameter, breast high, and 52.5 feet high. White spruce in this region reaches six inches on the stump, inside bark, in fifty years. Owing to the slow growth and to the nature of the topography and soil, it does not seem advisable to attempt artificial reforestation with white spruce in this region except in the favorable draws and pockets.

Near Cook the soil is a very heavy clay, averaging heavier than any other soil on which white spruce was found. The stands were denser than in any other region examined, but the growth, though very good, was not quite so rapid as that found in some other regions. An acre measured in a young stand contained 560 trees, 295 of which were more than three inches in diameter and averaged 5.1 inches in diameter, breast high. The age of this stand was twenty-eight years. It contains 11¾ cords of merchantable pulpwood, and at the present rate of growth should produce an average tree, ten inches in diameter

breast high, in between fifty and sixty years, and a yield of approximately fifty cords of pulpwood per acre. It would pay to reforest state lands in this region with white spruce, as the returns in sixty years would be far above the investment and interest on the investment.

Fig. 5. White Spruce, Plot 4, Warroad

The soil near Warroad, as described elsewhere, is fairly heavy, tho it varies considerably. White spruce was more dense on the lighter soils in this region, the heavier soil being occupied more with balsam and popple, probably because the water table is very near the surface. The average of the soil samples showed that this soil was somewhat lighter than the average of the spruce soil for the whole northern part of the state, but owing to the high water table white spruce grows very well. The stand in which the sample plots were located was in excellent condition. The best sample acre measured contained 251 spruce trees, as well as a considerable amount of popple. The average height of the trees was 70 feet and the average age, ninety-three years; with an average diameter, breast high, of 10.03 inches. This stand compares favorably with yields of spruce in Germany on the best soil. (See Figure 5.) Under management, the Warroad soil should yield between 75 and 90 cords of pulpwood in

ninety years, and should support a stand of 400 trees between ten and eleven inches in diameter, per acre. The best plot at present contains about 23,000 board feet to the acre, or about fifty cords of pulpwood. It would be profitable to plant all state land of this type to spruce. It would yield more than four per cent on the money invested. These deductions are made solely upon the present stand, and as these trees have been subjected to numerous fires and to natural enemies, it is safe to suppose that a much higher revenue could be derived from spruce forests on this land if properly cared for, and if all of the vacant spots were made to yield lumber. Thinnings would also produce pulpwood; and the revenue, accordingly, would be very much greater than that from the natural stands. This stand of spruce produced some trees six inches on the stump at thirty-five years and eight-inch trees at forty-five years. Allowing 850 trees to the acre, at thirty-five years the yield would be about thirty cords of wood per acre. With 750 trees to the acre, this land would yield five cords in thinnings at thirty-five years of age and approximately forty cords in a final cutting at fifty years.

In the region around Northome, the trees are of the very best quality and compare in rapidity of growth to the best growth recorded for acre stands in Germany. The average age of these trees was ninety years, the average diameter, 12.4 inches. The number per acre varied from 80 in one acre plot to 170 in another, and the ages were ninety

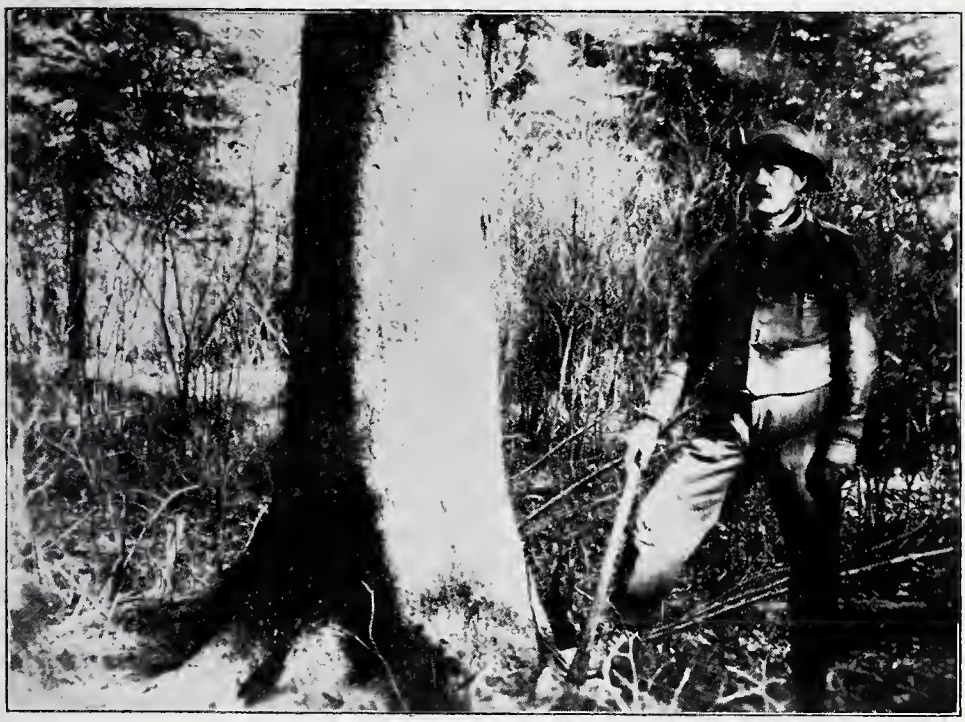

Fig. 6. Typical White Spruce More Than One Hundred Feet High, on Plot 2, at Northome

years in two plots, and ninety-two in the third. In ninety years this land would yield, under management, 100 cords of wood, or 50,000 board feet of lumber. It took this stand forty-six years to reach an average size of six inches in diameter. Some of the trees reached six inches in diameter in twenty-eight years. Judging from the average growth of the trees now on the ground, a fully stocked plantation on this soil, with 680 trees to the acre, would yield about fifty cords of merchantable pulpwood in forty-six years, including thinnings. (See Figure 6.) The soil at Northome seems to be particularly adapted to white spruce.

The soil in the region around Effie has been described in another part of this bulletin, and is quite similar to that found near Northome. The fastest growing spruce was found in soil which had a moisture equivalent of 28 per cent. One plot contained 52 trees to the acre, with an average diameter of 12.6 and an average age of one hundred and five years. Another plot on heavier soil, contained 126 trees which had an average diameter of 10.6 inches and were ninety-one years old. This plot at fifty years of age averaged 7.5 inches in diameter, and averaged 6.5 inches in forty years, altho many trees in the plot far exceeded these figures. For instance, one tree reached 10 inches in diameter in forty years and another 12.1 inches in fifty years. Some of the suppressed trees were 3.3 inches in diameter at fifty years, but these were in very crowded clumps. The growth in this region is about as good as any found in the state, but the density is not so great. It seems probable that this land, under good management, would yield as much as the best spruce land in Germany. For instance, 300 trees at the rate of growth shown by sample trees should yield from 80 to

Fig. 7. Base of Tree 101 Feet High and 103 Years Old, at Effie

90 cords of wood at ninety years, while 700 trees to the acre at 6.5 inches diameter should yield 6 cords in thinnings and 45 cords at the end of forty years. This rate of growth would more than pay the cost of establishing spruce forests in this region and would yield a fine profit to the state. (See Figures 7 and 8.)

Tables VI and VII show the average growth in height and diameter of white spruce under good conditions in the different regions.

TABLE VI

GROWTH IN HEIGHT OF WHITE SPRUCE IN DIFFERENT REGIONS

Region	Years required to reach a height of	
	Thirty feet	Sixty feet
Horse Lake	33	90
Cook	26	..
Warroad	30	78
Northome	32	84
Effie	39	82
Kelliher	32	60

TABLE VII

GROWTH IN DIAMETER OF WHITE SPRUCE IN DIFFERENT REGIONS

Region	Years required to reach diameter breast high of					
	6 Inches		8 Inches		12 Inches	
	Average growth	Best growth	Average growth	Best growth	Average growth	Best growth
Horse Lake	50	45	65	59	100	90
Cook	35	30	..	..	..	..
Warroad	34	28	46	33	66	49
Northome	42	28	51	33	62	44
Effie	44	28	54	32	70	48
Kelliher	40	20	52	23	70	41

TABLE VIII

TOTAL YIELD ON ACRE PLOTS

Plot	Balsam		Spruce		Popple		Total	
	Cords	Bd. ft.	Cords	Bd. ft.	Cords	Bd. ft.	Cords	Bd. ft.
Cook—								
Plot 1	....	....	....	....	28	6,300	28	6,300
Plot 2	34	12,000	9	4,000	....	....	43	16,000
Plot 3	4½	....	11¾	....	....	....	16¼	....

TABLE VIII—*Continued*
TOTAL YIELD ON ACRE PLOTS

Plot	Balsam		Spruce		Popple		Total	
	Cords	Bd. ft.	Cords	Bd. ft.	Cords	Bd. ft.	Cords	Bd. ft.
Horse Lake—								
Plot 1.....	....	....	1¼	800	10	4,000	11¼	4,800
Warroad—								
Plot 1.....	....	....	....	....	27	8,500	27	8,500
Plot 2.....	1	....	12¼	5,750	13	4,500	26¼	10,250
Plot 3.....	12	Few	2½	1,100	13	4,300	27½	5,400
Plot 4.....	....	....	52	23,000	....	....	52	23,000
Northome—								
Plot 1.....	5	....	27	13,000	....	1,600	32	14,600
Plot 2.....	¾	Few	42½	19,000	....	....	43¼	19,000
Effie—								
Plot 1.....	14	....	15	7,000	8	4,000	37	11,000
Plot 2.....	2	750	29	14,000	....	....	31	14,750
Plot 3.....	....	....	....	....	43	17,000	43	17,000
Plot 4.....	½	....	27	12,000	....	....	27½	12,000

TABLE IX
YIELD OF WHITE SPRUCE ON ACRE PLOTS

Region	Trees per acre	Average diam.*	Average height	Average age	Yield	
		Inches	Feet	Years	Cords	Bd. ft. M.
Horse Lake—Sec. 29, T. 65, R. 11.....	6 to 8	10-12	70.0	103	1¼	.....
Cook—Sec. 17, T. 62, R. 18, Plot 2.....	32	12.2	70.0	†	9	.....
Cook—Sec. 1, T. 62, R. 19, Plot 3.....	563 295 over 3 in.	5.1	32.4	28	11¾	.....
Warroad—Sec. 1, T. 62 N., 37 W., Plot 2.....	38 over 4 in.	12.3	80.0	100	12¼	5¾
Warroad—Plot 3.....	8	12.4	75.0	†	2½	.....
Warroad—Plot 4	251	10.3	70.0	93	52	23
Northome—Sec. 25, T. 151, R. 29 W., Plot 1.....	82 over 3 in.	12.4	85.0	90	27	13½
Northome—Sec. 19, T. 151 N., R. 28 W., Plot 2....	170	11.0	72.0	92	42½	19
Effie—Sec. 26, T. 62, R. 26 W., Plot 1.....	28 over 9 in.	15.7	87.0	106	15	7
Effie—Sec. 26, T. 62N, R. 26 W., N.E. ¼-N.E. ¼, Plot 2	82 over 3 in.	12.6	86.0	105	29	...
Effie—Sec. 21, T. 62, R. 25 N., S.W., S..E, Plot 4	126	10.6	74.0	91	30	13

* All measurements for diameter were taken 4½ feet above ground.

† In two of the plots which were on private land, permission could not be obtained to cut enough trees to learn the average age.

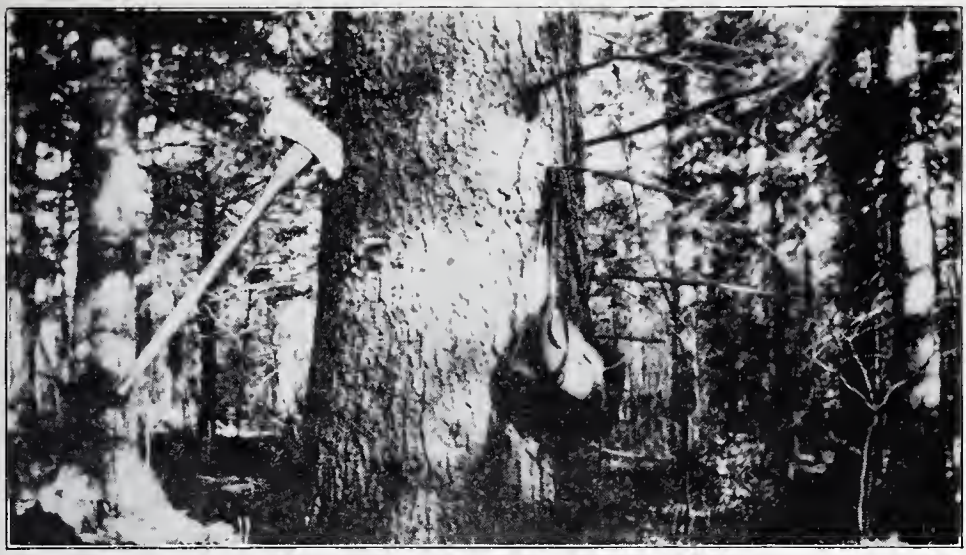

Fig. 8. White Spruce Nearly Three Feet in Diameter, on Plot 1, at Effie

VOLUME STUDIES

The greater part of the volume studies was conducted at a camp of the Crookston Lumber Company, near Kelliher, Beltrami County. The timber cut here averages twenty per cent white spruce and contains trees of all sizes, affording an exceptional opportunity for such a study. The soil is a light clay, well drained but moist, and ideal for the growth of white spruce. It is very much the same type of soil as that found in the Effie plots. Four hundred trees were measured.

All possible precautions were taken to insure accuracy. The calipers used were adjusted daily, and diameters were taken twice at each section wherever possible, in order to minimize the effect of irregularities in the trees. The measurements were taken as soon as possible after the trees were felled by the sawyers, before they were covered by other trees or debris. Starting at the stump, the stump height was taken, and its diameter inside and outside the bark, then the diameter at breast height, and after that the diameter outside the bark at each eight-foot section, beginning at the butt of the first log, and continuing to a diameter of three inches. The total height of each tree was measured and the thickness of the bark at the end of each eight-foot log. The age of the tree was obtained by counting the rings at the stump, and its rate of growth by measuring from the center, along an average radius, to every tenth ring.

The volume of each tree was figured in three different ways:

(1) By using measurements taken in the field, and the formula—V equals L $\left(\frac{B}{2}\right.$ plus B1 plus B2 plus B3 plus $\left.\frac{Bn}{2}\right)$ in which L is the length of each section and B1, B2, etc., are the basal areas of each section.

(2) By using Schiffel's formula—V equals H (0.16B plus 0.66b) in which H is the total height of the tree, B is the basal area breast high, and b is the basal area at the middle point of the tree. The total volume of the 400 trees as obtained by Schiffel's method was one-half of one per cent greater than that obtained by measuring every eight feet. This shows that Schiffel's method may unhesitatingly be applied to white spruce with assurance of accurate results.

(3) By applying the Scribner rule and scaling each tree in eight-foot logs. From this computation was obtained a converting factor for changing cubic measure to board measure.

By computing the volume both outside and inside the bark, the percentage of bark was found to vary from 15 in the smaller trees to 10 in the larger ones. These figures may be of value to shippers of pulpwood, who may find it profitable to reduce their freight rates by peeling the pulpwood before shipment. The percentage of bark in different sized trees is shown in Table X and Figure 10.

Heights have been averaged and correlated with the age and diameter of the trees, to show what height to expect at a given age and to ascertain the taper at various diameters. The growth of trees in height will, of course, vary with the site, so that these figures could be applied to spruce only when growing on a similar site.

Fig. 9. Maximum Density of White Spruce at 100 Years of Age
The average is 251 trees, about twenty-three hundred board feet to the acre.

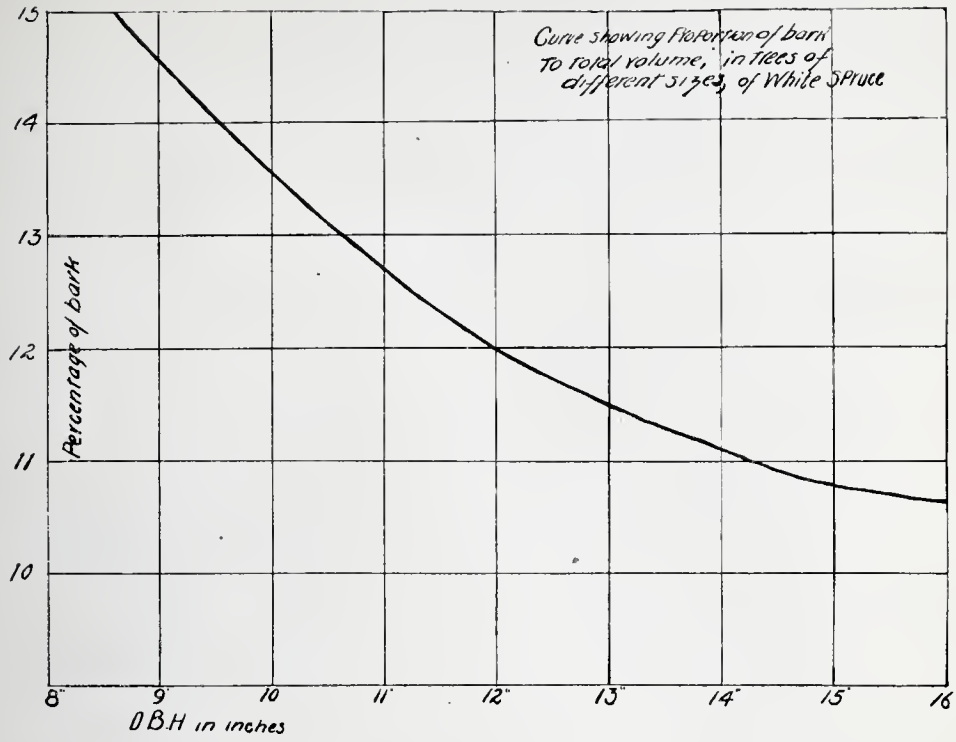

Fig. 10. Percentage of Bark in Different Sized Trees

TABLE X

Percentage of Bark in Different Sized Trees*

Diameter Breast High Inches	Bark Per cent
8.5	15.1
10.7	12.7
12.7	11.8
16.1	10.6

* Based on the measurements of 400 trees at eight-foot intervals and the separate computation of the volume of each stick with bark and without bark.

The age and diameter of the trees have been tabulated in order to show the average height and diameter at any given age, and also to show how long it would take under similar conditions to produce trees of any given size.

The taper inside of the bark of an average white spruce in the stand at Kelliher is best shown by the taper curve based on the diameter, breast high, inside the bark, Figure 11 and Table XI.

Five hundred feet, board measure, to a cord is the common figure used in converting board feet to cords, and 96 cubic feet to a cord in converting cubic feet to cords.

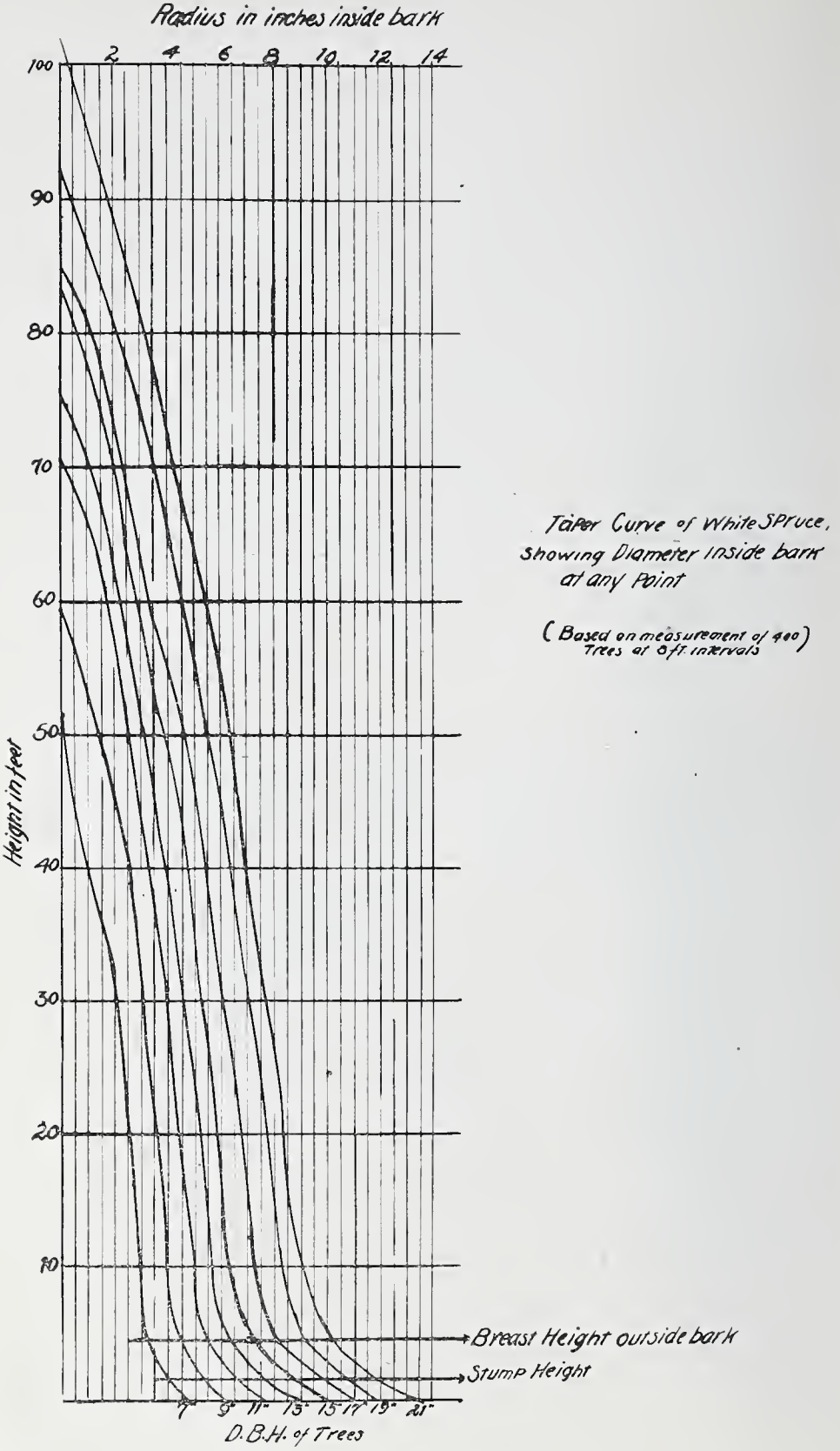

Fig. 11. Taper Curve of White Spruce

TABLE XI

Taper of White Spruce Inside Bark, Based on 400 Trees

Diameter breast high	Height stump	Stump D. I. B.	Total height	Diameter inside bark at eight-foot intervals										
				8	16	24	32	40	48	56	64	72	80	88
Inches	In.	In.	Ft.	In.	In.	In.	In.	In.	In.	In.	In.	In.	In.	In.
7	16.0	7.8	7.8	6.1	5.4	4.7	3.6	1.5	....	...	...	...	...	...
8	15.7	9.1	54.7	6.8	6.1	5.3	4.3	3.2	1.5	...	...	...	...	...
9	16.0	10.4	59.2	7.8	7.1	6.3	5.3	4.0	2.9	1.1	...	...	...	...
10	16.0	12.0	63.7	8.7	8.0	7.2	6.3	5.2	3.8	2.2	...	...	...	...
11	17.0	13.0	70.7	9.7	8.9	8.1	7.2	6.2	5.2	4.3	2.0	...	...	...
12	17.7	14.1	72.8	10.4	9.6	8.8	7.9	6.9	5.7	4.2	2.5	...	...	...
13	19.3	15.4	75.1	11.3	10.5	9.6	8.7	7.5	6.5	5.1	3.4	...	...	...
14	19.8	16.4	82.2	12.1	11.3	10.8	9.6	8.5	7.4	6.1	4.6	3.1	...	...
15	19.5	17.8	83.8	12.8	11.9	11.0	10.1	9.0	7.6	5.8	4.9	3.1	...	...
16	20.5	18.7	82.2	13.8	12.8	11.9	10.9	9.7	8.1	6.8	5.2	3.7	1.2	...
17	20.4	20.1	84.7	14.5	13.4	12.5	11.6	10.3	9.1	7.4	5.6	4.0	1.6	...
18	19.5	21.3	89.7	15.6	14.8	14.0	12.8	11.6	10.4	9.1	7.1	5.4	3.1	...
19	21.4	21.7	91.6	16.8	15.5	14.6	13.4	12.4	11.1	9.6	8.0	6.2	3.8	1.9
20*	....	....	....	....	....	....	....	....	....	....	...	...	...	...
21	20.3	23.8	101.9	18.1	16.9	16.1	14.9	13.9	12.8	11.3	9.8	7.7	5.9	3.3

* Not enough trees to insure a dependable average.

No constant factor can be used, however, because the factor varies with the size, taper, straightness, and soundness of the logs measured. It is obvious that a stand of spruce might be composed of six- or seven-inch trees and contain a large number of cords and cubic feet, and yet scale and saw out very little merchantable lumber, while a stand composed of a smaller number of trees with an average diameter of 12 inches might contain the same number of cords and cubic feet, and yet yield a much larger amount of merchantable lumber.

Table XII and Figure 12, based on the measurement of 400 white spruce trees, show the ratio of board feet to cubic feet in trees between 7 and 20 inches in diameter, breast high.

TABLE XII

AVERAGE NUMBER OF BOARD FEET TO EACH CUBIC FOOT, BASED ON DIAMETER BREAST HIGH, OUTSIDE BARK

Diameter breast high	Average height	Board feet to one cubic foot
Inches	Feet	
7	50	1.4
8	55	2.4
9	60	4.3
10	65	4.8
11	70	5.2
12	72	5.4
13	75	5.5
14	78	5.6
15	80	5.7
16	82	5.9
17	85	6.0
18	90	6.2
19	95	6.3
20	100	6.4

TABLE XIII

RELATION BETWEEN DIAMETER OF STICK AND VOLUME OF WOOD*

	Pieces measured	Eight-foot sticks per cord	Average diameter, inches	Cubic feet per cord
Pile 1	663	66.3	5.76	96.01
Pile 2	592	70.0	5.60	95.68
Pile 3	778	73.0	5.42	93.68

* The sticks measured ranged from three to eighteen inches in diameter.

TABLE XIV

VOLUME AND HEIGHT AS RELATED TO DIAMETER, BREAST HIGH, INSIDE BARK IN NATURAL MIXED STANDS

Diameter breast high (Inside bark)	Height	Volume		
		Inside bark		Including bark*
Inches	Feet	Cu. Feet	Bd. Feet	Cords
7	51.6	6.53	9.2	0.06
8	54.6	8.11	19.5	0.073
9	59.3	11.10	48.4	0.1
10	63.2	14.75	71.3	0.12
11	70.1	18.93	100.6	0.17
12	72.3	23.70	123.2	0.21
13	74.2	28.34	160.0	0.25
14	82.7	34.28	190.0	0.3
15	83.0	39.21	226.2	0.34
16	83.2	44.96	269.3	0.4
17	84.5	52.72	246.3	0.45
18	89.7	64.24	407.3	0.53
19	91.1	70.58	497.5	0.6
20	101.0	88.41	542.5	0.75
21	102.5	94.07	612.5	0.81

* Taken to four-inch top.

These figures are based on measurement and individual computation of 400 trees in a white pine-white spruce stand with a mixture of some hardwoods. The stand was typical of the spruce type in the region of Red Lake. Many of the trees have been suppressed at one time in their development.

TABLE XV

VOLUME INSIDE BARK OF DOMINANT TREES BASED ON AGE AND THREE-INCH TOP*

Age	D. B. H.	Height	Volume		
Years	Inches	Feet	Cu. Feet	Cords	Bd. Feet
10	1.0	8	...	...	...
20	3.0	20	0.38	...	...
30	5.6	35	2.4	0.02	10
40	8.4	50	7.5	0.08	30
50	10.9	65	14.6	0.15	80
60	12.9	75	25.1	0.27	135
70	14.9	85	39.4	0.42	225
80	16.9	90	56.6	0.61	320
90	18.7	95	72.5	0.7	450
100	20.6	100	92.6	0.93	590

* This table is based on the dominant trees in the Kelliher region and shows the results to be expected from plantations on this type of soil.

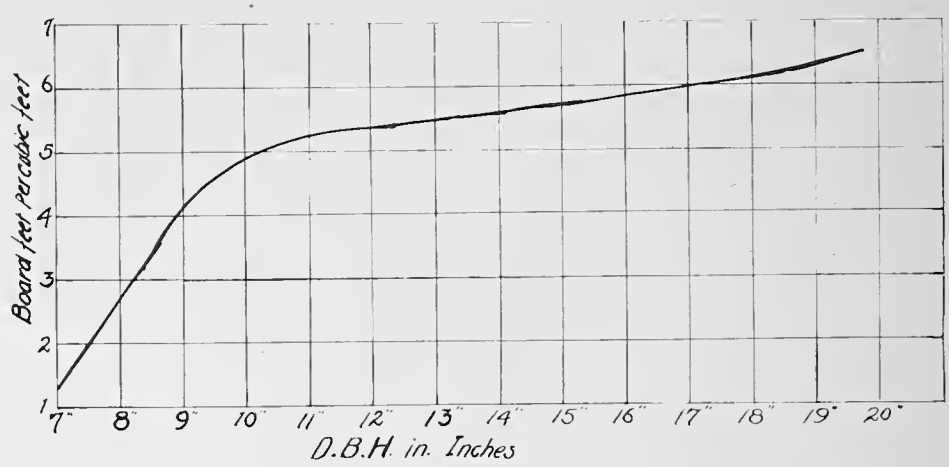

Fig. 12. Ratio of Board Feet to Cubic Feet in White Spruce

POSSIBILITIES OF PRIVATE INVESTMENTS

The pulp and paper mills of Minnesota represent a very large investment. Their immediate source of raw material is mostly the spruce growth of the swamps. In a very short time it will be hard for most of the mills to obtain raw material within a reasonable distance. The increased cost of transportation as the supply is pushed back farther and farther, together with the growing scarcity of the supply, will necessarily increase the cost of the raw material at the mill as it already has in New England, New York, and Wisconsin. For instance, the price of peeled pulpwood at the mill in New York averaged $14 per cord two years ago, an advance of about thirty per cent over the price of four years ago. Owing to the war, this price has increased to $24. In Wisconsin it is reported to have reached $25 per cord, f.c.b. mill.

This brings up the question of whether it would not be a paying investment for mill owners to establish, near the mill, plantations of spruce that would furnish indefinitely an adequate supply of raw material. The data in this report indicate that this is feasible. The investment would not be so large as would be necessary now to buy and hold a supply as great as could be raised on a perpetual basis. Moreover, the ultimate exhaustion of any supply bought at the present time, no matter how large, is certain unless some measure is taken to perpetuate it.

What investment would be necessary to establish a plantation large enough to supply a mill using 25,000 cords of pulpwood annually, the first cut other than thinnings to be made in fifty years?

The data collected show that fifty cords per acre is a probable yield at the end of fifty years on the proper type of soil. The cut from 500 acres would be required to supply the raw material for a year. Therefore, 25,000 acres must be planted if a series is to be established that will supply the mill indefinitely.

This would entail the cutting of 500 acres and the planting of 500 acres after the first cut. In the start, it would be advisable to plant the tract in the first twenty-five years, if it were all purchased at one time.

It would probably be impossible to purchase 500 acres each year contiguous to the land previously purchased, so it would be necessary to purchase all or a greater part of the 25,000 acres at the start. This is a little over a township, and when bought in such a large quantity, should not cost over $5 per acre at the present time, deducting the value of the timber and young growth generally found on such land.

The cost of raising a cord of pulp wood on a fifty-five year rotation, figuring fifty cords to the acre at the end of fifty years, would be $2.25 per cord, allowing $5 per acre for the cost of the land and $7.50 per acre for the cost of planting, compounding the cost of land and planting at four per cent annually for fifty years. This presupposes that all the 25,000 acres were bought at one time and planted during the first twenty-five years.

Taxes and administration computed at 10 cents per acre per annum compounded at four per cent would amount to 31 cents per cord based on a yield of fifty cords to the acre at fifty years.

Taxes, of course, vary greatly in different regions, but the same ratio would hold true. For instance, with an annual tax of 20 cents per acre per year, under the same conditions, the cost of taxes would be 62 cents per cord.

It is estimated that thinnings on this fifty-year rotation would amount to eight or ten cords per acre without decreasing the final yield. These thinnings would to a considerable extent offset the cost of protection and taxes.

TAXING FOREST LANDS

The present system of taxation, if properly carried out, is unfair to the timber grower, because it provides for the repeated collection of taxes from the same crop, a condition which is not true in its application to the grower of farm crops. In farming operations, the crop is removed each year from the land which produces it, while in forest operations each year's crop must be stored on the ground until its accumulation in volume in the form of individual trees becomes suffi-

ciently large to make it worth while to remove it. In reality, this year's forest crop (the growth which takes place this year within the forest) may have to be held from one to fifty years before it can be removed from the land. According to our present system of taxation, it is retaxed each year during this period. If the same land had been devoted to the production of farm crops, each crop would have been removed during the year in which it was produced and hence would have been taxed only once.

How may the unfairness of the present system to the timber producer be corrected without injury to the interests of the general public? By the retention of the present system of taxation as far as the land itself is concerned, applying the present general property tax to the sale value of the unimproved cut-over land only, and the substitution of a yield tax on the stumpage value of the timber just before cutting, in place of the present system of annually repeating the tax on the same forest crop.

The unfairness of the present system of taxation as applied to the productive forest has already been recognized by several states—Connecticut, Massachusetts, New York, Pennsylvania, and Vermont—which have passed during the last six years forest taxation laws, putting in force the practical application of the principles just brought out. Perhaps the most carefully worked out of these special forest taxation laws is the one passed in 1914 by the Massachusetts legislature, after it had been empowered to act by a constitutional amendment. The salient provisions of this law are:

1. The land to which the law is applied must be registered with the State Forester and State Tax Commissioner, thus making the application of the law to any particular tract optional with the land owner.

2. The land so registered must be stocked either naturally or from planting with commercial trees within a limited period of time after registration.

3. The assessment of the land at the proper proportion of its sale value as unimproved untimbered land and the annual payment of the general property tax on this assessment.

4. The substitution of a six per cent yield tax, based on a fifty-year rotation in place of the present annually repeated tax, on the value of the merchantable timber.

A forest taxation law of this kind probably does not subject the timber producer to any greater hardship than the farm crop producer, and at the same time enables him to compute quite accurately the total cost of taxation; while the present system, if actually enforced, may leave nothing for the timber producer after the taxes are paid.